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ABSTRACT

A quantitative synthesis of multivariate studies in science education during the past ten years yields evidence to support a model of achievement in science very much like that currently proposed in the literature of expert problem-solving. Despite previous claims, spatial visualization and verbal ability predict additional variance in achievement beyond that which they share with general intelligence. Both are also components of most theories of expertise. Cognitive ability, scientific reasoning, and prior knowledge all add further variance to the regression equation, and are demonstrably separate in their contributions to scientific achievement. Quantitative ability does not appear to be uniquely separate from cognitive ability. These results suggest an instructional program that focuses more on domain-specific skills and knowledge than on generalized and problem-solving. (Author)

EVIDENCE FROM META-ANALYSIS FOR AN EXPERTISE MODEL OF ACHIEVEMENT IN SCIENCE

by

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Abstract

A quantitative synthesis of multivariate studies in science education during the past ten years yields evidence to support a model of achievement in science very much like that currently proposed in the literature of expert problem-solving.

Despite previous claims, spatial visualization and verbal ability predict additional variance in achievement beyond that which they share with general intelligence. Both are also components of most theories of expertise.

Cognitive ability, scientific reasoning, and prior knowledge all add further variance to the regression equation, and are demonstrably separate in their contributions to scientific achievement. Quantitative ability does not appear to be uniquely separate from cognitive ability.

These results suggest an instructional program that focuses more on domain-specific skills and knowledge than on generalized and problem-solving.

EVIDENCE FROM META-ANALYSIS FOR AN EXPERTISE MODEL OF ACHIEVEMENT IN SCIENCE

Introduction

Research comparing the performances of experts and novices within fields ranging from competitive chess to chicken sexing has revealed differences that are as much qualitative as they are quantitative. While it is true that the performance of experts is superior to that of novices, it is also the case that the strategies which they use are markedly different.

In addition, expertise is context specific. Chess masters have remarkable memory capacities, but only for chess positions. Map-makers have exceptional spatial skills, but only for the maps that they are expert with. So, it can be argued, must expert scientists and science students display skills that are very different from those of novices, but which are transferred only with extreme difficulty, and exceptionally infrequently, to new and unfamiliar domains.

The most prominent recent tradition of research in science education has been within the Piagetian framework, which posits, above all other hypotheses, the existence of invariant and developmental abilities that characterize all human thought. This has been a truly productive line of inquiry, with broad explanatory and predictive capabilities. However, even with the sophistication added by the neo-Piagetian school, this line of inquiry has been increasingly unable to account for the unique performances that are now being on the part of experts across many fields.

In contrast, examination of the performance of experts and novices suggests that context-specific abilities and background knowledge are much more significant in expert performance than more general intelligence or psychological abilities (Ericsson & Smith, 1991). General intelligence is less predictive of the success of experts, nor are experts particularly more intelligent than novices. Thus, the emerging theories of expertise focus to a much large extent on the background and experience of the practitioner than they do on more general psychological variables.

Review of the Literature

Despite recent movements to subdivide the intelligence concept, such as the Sternberg's Triarchic Model or Gardner's Multiple Intelligences, Spearman's g (general intelligence) is alive and well. Arthur Jensen, one of the concept's more forceful contemporary advocates, believes that this substrate of intelligence shares more variance with a greater range of cognitive activities than any other single factor (Sternberg, 1990).

It has been well accepted for almost a century that if any two types of ability are factorially distinct from one-another, they are verbal and spatial (Lohman, 1988). This has been given further credence more recently by the research of Sperry (1961) with commissurotomy patients, demonstrating the very different functions of left and right cerebral hemispheres, and studies of the types of solution to three-term series problems used by visual and analytic problem solvers (Sternberg, 1980). Again, however, g tends to absorb by far the greatest variance in any predictive equation, and the addition of terms for verbal and spatial ability often adds little to its explanatory power.

Spatial ability is especially difficult to define because, although many measures appear to be spatial in character, few of them cluster heavily into a single factor solution. In addition, the demonstrable contribution of spatial factors to achievement is often low. Indeed, Lohman states that "spatial tests add little to the prediction of success in traditional school subjects, even geometry, after general ability has been entered into the regression (1988, pg. 182).

The publication, in 1958, of The Growth of Logical Thinking From Childhood to Adolescence by Barbel Inhelder and Jean Piaget was a significant event for science education. Within a very short period of time this work had caught the attention of science educators, and ultimately led to more than a decade of research within the Piagetian paradigm. The product was a re-consideration of the psychological basis of science education and the acceptance of a constructivist position.

Modern theory in this area is described as neo-Piagetian, and involves an attempt to unify several separate psychological traditions. These include earlier visions such as functionalism and structuralism as well as more contemporary models of information processing and artificial intelligence. As is often the case, this effort has not gone smoothly (Beilin, 1987).

Science educators involved in this new synthesis have been most influenced by the work of Pascual-Leone (1969), which emphasizes particularly the importance of two performance factors, M-demand and field effects, in the completion of Piagetian tasks. If the subjects' mental capacities (M-space) are not adequate to the M-demand of the task, or if they are distracted by field effects, they will not be successful even if they are fully competent in the logical demands of the task.

In contrast to these variables, which are psychological in nature, another set of variables can be characterized as reflecting the idiosyncratic background and experience of the individual. These are most commonly associated with schooling, but it is entirely possible that they might be acquired elsewhere.

Interest in such background, or prior knowledge, variables has been generated recently by the research into the development of expertise (Ericsson & Smith, 1991). Of particular relevance to this issue was the contention by Chase and Simon (1973) that the major difference between experts and novices is in their access to relevant domain-specific knowledge.

Relevant prior knowledge is more easily defined in some fields than in others. In the case of chess, used by Chase and Simon, experts were able to recognize on sight approximately 50,000 chess positions. This is similar to the number of different words that a competent reader of the English language might be able to recognize. However, often also included within this group of acquired knowledge bases are information processing, problem solving, or meta-cognitive strategies that are not thought of as psychologically innate (Ericsson & Smith, 1991).

A tendency among educators, at least until recently, has been to concentrate on general problem-solving and reasoning skills, under the assumption that these will transfer to specific subject areas. In science education, this trend would be characterized by curricular initiatives such as the scientific literacy course discussed by Baker and Piburn (1990; 1991), whose purpose was to develop general skills that students could later apply in their subject area science courses. In the more general educational arena, it would be reflective of materials that emphasize direct teaching of thinking as a basic skill (deBono, 1981; Harnadek, 1976; Bransford & Stein, 1984). As a further example, the most recent catalog of Dale Seymour Publications has, in addition to sections on science, mathematics and language arts, one devoted solely to "Thinking Skills".

The emerging literature on expertise provides a challenge to such a general approach, and suggests as an alternative that closer attention be paid to the development of domain specific knowledge and skills. However, this contention still remains relatively untested, and it is within this framework that the current study was conducted.

Statement of the Problem

The options of teaching generalizable reasoning processes, and attempting to facilitate transfer across domain boundaries, versus teaching specialized skills within narrower settings, suggests a set of competing hypotheses. The test of these must of necessity rest in a comparison of the relative importance of general versus content specific skills and information to achievement in science. If generalized skills are more predictive of achievement, the first hypothesis would be accepted and the second rejected. On the other hand, should domain-specific variables be more predictive, the converse would be true.

Two approaches to conducting such a test suggest themselves. The first is an original study, with a single independent (achievement) measure and a large number of dependent measures of both general and specific skills and knowledge, administered to a single sample. As the normal criterion for multivariate statistics requires at least ten times as many subjects as variables, this would dictate a sizable sample. The alternative is a meta-analysis using aggregated data from a prior studies. The latter appears to be more manageable, and has been chosen for this study.

Three sets of independent variables have been chosen for this test. The first set are characterized as ability measures, and include verbal, spatial and general ability. The second are neo-Piagetian measures, and include field dependence-independence, memory capacity and cognitive level. The third are background and prior knowledge variables, and include scientific and quantitative reasoning and prior knowledge. The dependent variable is achievement in science.

The following research hypotheses will be tested:

h1: The independent contributions of spatial and verbal reasoning to achievement in science will be small after the variance shared with general intelligence has been accounted for.

h2: The independent contributions of mental capacity and field dependence-independence to achievement in science will be small after the variance shared with cognitive level has been accounted for.

h3: The independent contributions of background knowledge variables to achievement in science will be small after the variance shared with psychological variables has been accounted for.

Methodology

The procedure of meta-analysis was suggested by Glass (1976) as an alternative to other methods then in use for the review of prior research. In this study, it is used to compare the results of correlational studies. While a variety of procedures are available for weighting the values of correlation coefficients from different studies (Hedges & Olkin, 1985; Schmid, Koch, & LaVange, 1991), these have not been used in the few studies of this type to be found in the science education literature. Instead, the strategy of choice has been to collect a pool of similar correlation coefficients and to report their means and variances.

All issues of the Journal of Research in Science Teaching from 1983 through 1992 were reviewed. In most cases, correlation coefficients were extracted directly from the article. However, it was occasionally necessary to record a regression coefficient instead. Such coefficients "can be interpreted much like an ordinary coefficient of correlation" (Kerlinger, 1973. pg. 621). In a few studies an unusually large number of similar correlations were recorded, as for example the relationship between a variable and 3-5 separate examination scores in several different courses. In such cases, where it seemed suitable, a single average was computed and recorded.

Results

Publication over a ten-year period of the Journal of Research in Science Teaching yielded 44 articles which contained a total of 186 usable correlation coefficients. These were grouped into 37 different categories, and summary statistics were computed for each.

From among these, nine represented relationships between achievement in science and other variables (Table 1). Achievement measures included test and examination grades, gain scores from pre- to post-test, course grades, grade point average, and achievement on standardized tests.

Six psychological variables were chosen. These were general ability, verbal and spatial reasoning, field dependence-independence, mental capacity, and cognitive ability. A factor analysis of these was conducted, and they all clustered into a single factor with loadings of between .53 and .81, and an eigenvalue of 3.19. No other factor with an eigenvalue of more than 1.00, the normal default option, could be computed. From this it was concluded that all of the psychological variables came from a single psychometric pool of items, and that there was no statistical basis for their classification. Thus they were organized into two groups on the basis of a priori theoretical constructs; ability and neo-Piagetian. Two general categories of background or prior knowledge were aggregated; procedural and declarative. Procedural knowledge consisted of measures of scientific and quantitative reasoning. Declarative knowledge included variables which, in the original study, had been characterized as measuring prior knowledge. This last group ranged widely, including pre-tests, standardized achievement tests, prior course work, and Grade Point Average.

<u>Comparison With Prior Meta-Analyses</u>

Three meta-analyses of the relationship between achievement and other factors were completed and reported in 1983. Of these, two can be compared directly with this study. The work of Steinkamp and Maehr (1983) dealt primarily with gender differences, and their analyses were conducted separately for males and females. For example, they reported correlation coefficients between cognitive ability and achievement of .36 for males and .32 for females. This is slightly lower than the value of .44 for this same relationship reported here.

One study (Fleming & Malone, 1983) reports a greater variety of data, is more comparable to, and shows results that are much more like those reported in this study (Table 2). They are in general quite similar, and yield confidence not only in the stability of the relationships through time, but also in the technique of meta-analysis itself.

The Effects of Ability

Five relationships between general ability and achievement in science were obtained in this study. The ability measures used were the abstract reasoning sub-test of the Differential Aptitude Test (DAT), the Primary Mental Abilities Test, Raven Progressive Matrices, the School and College Abilities Test, and the Otis-Lennon Intelligence Test.

The most commonly accepted primary components of spatial ability are visualization and spatial orientation (Ekstrom, French, Harman & Dermen, 1976). Three of the five relationships found for this study were with spatial rotations. The remaining two were between achievement and the spatial and mechanical reasoning sub-tests of the Differential Aptitude Test (DAT).

Verbal abilities were measured in four studies, and their correlation with achievement computed. The measures used were the vocabulary sub-test of the Stanford Achievement Test, the verbal sub-test of the Cognitive Abilities Test and the Descriptive Test for Language Skills. Although none are counted among the more traditional measures of verbal ability, they seem suitable for the purpose addressed in this study.

Sufficient information was gathered in the course of this study to conduct a multiple regression analysis of the impact of general, verbal and spatial ability on achievement in science (Table 3). Only one correlation was missing, that between verbal and spatial ability, and a value of .34 was obtained from Lohman (1988, pg. 194).

In a test of previous assertions of the relative importance of these three variables, achievement was regressed against verbal ability, followed by spatial ability and then by general ability (Table 3). This order of entry was specifically chosen to test the claim that the variance in success in school subjects rests largely in measures of general intelligence.

Almost 50% of the variance in achievement is shared with the measures of verbal and spatial ability, and there is virtually no subsequent increase in explained variance with the subsequent entry of general ability. The Betas for both verbal and spatial ability are large, and very similar to one another, whereas the Beta for general ability is so small as to have virtually no meaning.

From this result, it is necessary to reject the first hypothesis, that variance in achievement can be explained largely by the variable of general intelligence. In fact, the opposite is true. We must look to individual differences in verbal <u>and</u> in spatial ability to predict achievement in science.

Neo-Piagetian Factors

Mental capacity is most often measured by means of digit span tests, in which a subject is asked to repeat strings of letters or numbers. However, Burtis and Pascual-Leone created a measured called the Figural Intersection Test specifically to measure M-space.

Although the concept of field-ground is an old one in psychology, the field effects emphasized in Pascual-Leone's theory refer more specifically to the phenomenon of field-dependence/independence (FDI) formulated by Witkin (Witkin, Dyk, Faterson, Goodenough & Karp, 1962). Witkin's original work, conducted with subjects in an inclined room, characterized people on a continuum from those who were influenced most heavily by internal (the force of gravity) to external (the room, or field) cues. Those latter individuals were called field-dependent. Subsequently, Witkin turned to the Embedded Figures Test to measure this same quality, which he then called restructuring. Those subjects who were unable to restructure were unsuccessful on the Embedded Figures Test and were thus field-dependent.

The Embedded Figures Test is similar to the Hidden Figures Test, which itself is an adaptation of the older Gottschaldt Figures test popularized by Thurstone (Ekstrom, French, Harman & Dermen, 1976). Both of these latter instruments are traditionally considered to be measures of flexibility of closure, which some authors consider to be an element of spatial ability and others contend is related to the ability to break set (Lohman, 1988).

Measures of cognitive ability included the Developing Cognitive Abilities Test, the Group Assessment of Logical Thinking, several forms of the Lawson Test of Formal Reasoning, the Propositional Logic Test, the Test of Logical Thinking, and a variety of clinical Piagetian measures.

The question of whether or not cognitive ability itself contributes to achievement beyond that explained by FDI and mental capacity was tested by regressing achievement against both neo-Piagetian variables and then against cognitive level (Table 4). The results indicate that the increase in explained variance in achievement with the addition of cognitive ability is quite large, and that the Betas associated with FDI and mental capacity are so low as to have virtually no meaning.

Thus, the second hypothesis is accepted. Cognitive level itself contains almost all of the variance shared between neo-Piagetian variables and achievement, and has additional explanatory power as well.

The Nature of Prior Knowledge

Only recently have science educators begun to include background knowledge as a relevant variable in their studies of achievement. Three categories of measure have emerged during this study. The first is scientific reasoning, the second quantitative reasoning, and the last is content and conceptual knowledge. The first two are characterized as procedural knowledge, and the last as declarative knowledge.

The more familiar measures of scientific reasoning skill are process measures such as the Test of Integrated Process Skills (TIPS) or the Process of Biological Investigations Test. However, they are also very similar in many respects to the most commonly used measures of cognitive ability, such as the Lawson Test of Formal Operations or the Test of Logical Thinking. Both types of measure have more often been used as dependent than as independent variables in science education research. However, it is at least as reasonable to think of them as measures of generalized background knowledge that would be useful in promoting achievement.

Quantitative reasoning is often represented in research studies as a variable similar to ability or cognitive level, with the implication that it has underlying psychological properties. Indeed, some measures share properties with measures of cognitive level in that they both contain items requiring proportional reasoning. Again, it seems reasonable to think of quantitative reasoning as a type of background knowledge.

Four types of scientific and conceptual knowledge variables were identified in this study. The first are standardized assessments of achievement in science, such as the California Achievement Test or College Board examinations. The second are pre-tests, sometimes taken from item banks and often similar or identical to the post-test used in the same study. Third are the number or type of misconceptions held by students. Finally are in earlier course work, as for example science grade-point average.

The available matrix of correlation coefficients does not allow a full test of the third hypothesis. In particular, coefficients of correlation between verbal and spatial reasoning some of the variables of background knowledge were not found during the literature search. Thus, two separate tests were completed.

In the first, achievement was regressed against cognitive level and quantitative and scientific reasoning (Table 5). In this instance, only quantitative reasoning failed to achieve a notable Beta, or to significantly increase the explained variance in achievement. The contribution of scientific reasoning was stronger than that of cognitive level, and hypothesis three is rejected.

In the second test, achievement was regressed against scientific reasoning and prior knowledge (Table 6). Both variables achieved meaningful Betas, and independently contributed to the variance in achievement in science.

The logic of these two tests requires discussion. Although the psychological variables included in the regression were limited to cognitive ability, the first test demonstrated the relative independence of procedural background knowledge in predicting achievement. The second demonstrated the independence of procedural and declarative knowledge. Unfortunately, once again empty cells in the correlation matrix prevented including quantitative ability in this test. However, the previous analysis suggested that this was not a major flaw. The two regression analyses taken together acted as surrogate for a more desirable single and comprehensive regression that was prohibited by the presence of empty cells in the correlation matrix.

DISCUSSION

Among several emerging re-conceptualizations of intelligence is the model proposed by Howard Gardner (1983). He argues for a multiplicity of intelligences whose authenticity rests more in practice than in psychometrics. Specifically, one of his criteria for the acceptance of an intelligence is its emergence as an area of expertise in some culture.

No one would argue against the significance of verbal skills in our world and, indeed, verbal ability is one of Gardner's seven intelligences. In evidence, he cites a number of societies within which the development of rhetorical skills and public speaking are important prerequisites to positions of prestige.

There is less discussion in the literature on expertise about the role of spatial ability. The exception seems to be chess, where "superior spatial ability often is assumed to be essential" (Ericsson & Smith, pg. 6). One set of results linking chess masters to superior ability in memory tests involving the position of chess pieces indicated that a factor in their performance might be superior visual memory. Using his expertise criterion, Gardner includes spatial ability as an intelligence on the basis of evidence of cultures where children are screened for exceptional spatial ability and subsequently trained for specific roles, such as navigator, in their culture.

Although spatial skills are rarely part of the curriculum, there is extensive evidence that they have an claim equal to that of verbal skills for our attention. Research in science education demonstrates that they can be quite successfully taught (Lord, 1985, 1987), and such instruction has been shown to improve conservation task performance for young children (Dolecki, 1981) and physics achievement for college students (Pallrand & Seeber, 1984).

Studies of expertise have demonstrated the importance of memory in performance as diverse as that of bartenders and chess masters. Yet this variable did not emerge here as an important one. One possible explanation is that the measurement of memory in abstract settings, such as the Figural Intersections Task, does not tap the same dimension as expert performance. In fact, experts seem to violate the rule (Miller, 1956) that strings of information more than nine units long are almost impossible to remember. It seems that they use chunking strategies that were unavailable to novices and that allowed them to remember substantially more. This is a significant and unresolved question that deserves further study.

The failure of quantitative reasoning to emerge as a major factor in scientific achievement is also surprising, especially in light of a variety of studies indicating its importance (Hudson & Rottman, 1981; Wollman & Lawrenz, 1984). It apparently does not contribute any variance that is not also shared by cognitive ability and scientific reasoning.

The characterization of prior knowledge in this study uses the same distinction that is implicit in the dichotomy of declarative and procedural. In the first category are those measures that include standardized achievement test scores, pre-tests on curriculum relevant items, or prior achievement in science. Procedural knowledge is most commonly characterized as scientific process skill. The analyses presented in this paper demonstrate the independent and important contributions of both declarative and procedural knowledge in predicting achievement. In fact, the variance in achievement associated with these (22%) is approximately the same as that associated with the ability variables (27%) and the neo-Piagetian variables (21%).

These results allow acceptance of a model for the development of scientific achievement that is not unlike the contemporary view of expertise. General intelligence, although a factor, is surprisingly unimpressive as a predictor of scientific achievement, as it is of other forms of outstanding performance. On the other hand, content-specific background knowledge, both procedural and declarative, emerges as a more decisive factor in predicting achievement than has been previously demonstrated.

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Table 1. Mean correlations between scientific achievement and background variables.

ACHIEVEMENT IN SCIENCE	MEAN CORRELATION	STANDARD DEVIATION	NUMBER OF STUDIES
x Verbal ability	.40	.25	4
x Spatial ability	.41	.22	5
x General ability	.41	.22	5
x FDI	.29	.18	13
x Mental capacity	.21	.20	8
x Cognitive level	.44	.15	15
x Quantitative reasoning	.35	.22	14
x Scientific reasoning	.40	.16	6
x Prior knowledge	.39	.12	8

Table 2. Comparison of results of meta-analysis by Fleming and Malone and of this study.

ACHIEVEMENT IN SCIENCE	Fleming & Malone	This Study
x General ability	r=.43 D=.22 n= 42	r=.41 SD=.22 n= 5
x Verbal ability	r=.41 D=.16 n= 5	r=.40 SD=.25 n= 4
x Quantitative ability	r=.42 RD=.19 n= 13	r=.35 SD=.22 n= 14

Table 3. Regression of achievement against ability variables.

	(1)	(2)	(3)	(4)
(1) General ability	-	.74	.53	.41
(2) Verbal ability	.74	-	.34*	.40
(3) Spatial ability	.53	.34*	-	.41
(4) Achievement	.41	.40	.41	-

* see text

DEPENDENT VARIABLE = ACHIEVEMENT

Independent Variable	Multiple r	Multiple r-squared	Beta
Verbal ability	.400	.160	.247
Spatial ability	.495	.245	.286
General ability	.497	.247	.076

Table 4. Regression of achievement against neo-Piagetian variables.

	(1)	(2)	(3)	(4)
(1) FDI	-	.37	.40	.29
(2) Mental	.37	-	.37	.21
(3) Cognitive	.40	.37	-	.44
(4) Achievement	.29	.21	.44	-

DEPENDENT VARIABLE = ACHIEVEMENT

Independent Variable	Multiple r	Multiple r-squared	Beta
Mental capacity	.210	.044	.021
FDI	.310	.096	.130
Cognitive level	.458	.209	.380

Table 5. Regression of achievement against psychological and procedural knowledge variables

		(1)	(2)	(3)	(4)
(1)	Cognitive level	-	.50	.57	.44
(2)	Quantitative reasoning	.50	-	.49	.35
(3)	Scientific reasoning	.57	.49	-	.48
(4)	Achievement	.44	.35	.48	-

DEPENDENT VARIABLE = ACHIEVEMENT

Independent Variable	Multiple r	Multiple r-squared	Beta
Cognitive level	.440	.194	.218
Quantitative reasoning	.465	.216	.088
Scientific reasoning	.521	.271	.313

Table 6. Regression of achievement against prior knowledge variables.

		(1)	(2)	(3)
(1)	Scientific reasoning	-	.40*	.40
(2)	Content knowledge	.40*	-	.39
(3)	Achievement	.40	.39	-

* see text

DEPENDENT VARIABLE = ACHIEVEMENT

Independent Variable	Multiple r	Multiple r-Squared	Beta
Scientific reasoning	.400	.160	.291
Prior knowledge	.472	.223	.274

ACHIEVEMENT X GENERAL ABILITY	
MEAN =	.41
STANDARD DEVIATION =	.22
NUMBER =	5

DAT Abstract Reasoning x grade point average (Wittig, Sasse & Giacomi, 1984).	.44
Primary Mental Abilities Test x course grade (McCammon, Golden & Wuensch, 1988).	.23
Raven Progressive Matrices x chemical calculations (Niaz & Lawson, 1985).	.46
School and College Ability Test x gain-score (McGarity & Butts, 1984).	.20
Otis-Lennon Intelligence Test x Stanford Achievement Test -science (Ronning, McCurdy & Ballinger, 1984).	.74

ACHIEVEMENT X COGNITIVE LEVEL	
MEAN =	.44
STANDARD DEVIATION =	.15
NUMBER =	15

Group Assessment of Logical Thinking x course grade (Bitner, 1991).	.51
Group Assessment of Logical Thinking x chemistry problems (Niaz & Robinson).	.34
Classroom Test of Formal Operations x SRA Science (Germann, 1989).	.54
Lawson Test of Formal Reasoning x class exams (Niaz, 1989).	.67
Lawson Classroom Test of Scientific Reasoning x pos-test (Lawson & Worsnop, 1992).	.50
Lawson Classroom Test of Scientific Reasoning x gain scores (Lawson & Worsnop, 1992).	.21
Lawson Classroom Test of Formal Reasoning x post-test (Lawson, 1983).	.18
Lawson Classroom Test of Formal Reasoning x stoichiometry problems (Niaz & Lawson, 1985).	.49
Test of Logical Thinking x ACER test bank items (Chandran, Treagust & Tobin, 1987).	.38
Test of Logical Thinking x chemical calculations (Chandran, Treagust & Tobin, 1987).	.41
Test of Logical Thinking x lab applications test (Chandran, Treagust & Tobin, 1987).	.36
Piagetian tasks x delayed pos-test (Gipson, et al., 1989).	.55
Proportionality x course grade (Hudson, 1986).	.22
Proportionality x midterm & final exam scores (Roth, 1990).	.63
Propositional Logic Test x course grade (Piburn, 1990).	.57

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ACHIEVEMENT X FIELD DEPENDENCE/INDEPENDENCE	
MEAN =	.29
STANDARD DEVIATION =	.18
NUMBER =	13

EMBF x course grade (Bodner & McMillen, 1986).	.32
Find-a-Shape x course grade (Pribyl & Bodner, 1987).	.23
Find-a-Shape x exam grades (Carter, LaRussa & Bodner, 1987).	.18
Gottschaldt Figures Test x stoichiometry problems (Niaz & Lawson, 1985).	.38
Group Embedded Figures Test x ACT-composite (McMurry & Beisenherz, 1991).	.73
Group Embedded Figures Test x Stanford Achievement Test-science (Ronning, McCurdy & Ballinger, 1984).	.42
Group Embedded Figures Test x midterm & final exam (Roth, 1990).	.40
Group Embedded Figures Test x exam score (Crow & Piper, 1983).	.36
Group Embedded Figures Test x post-test (Lawson, 1983).	.31
Group Embedded Figures Test x chemistry problems (Niaz & Robinson, 1992).	.22
Hidden Figures Test x ACER items (Chandran, Treagust & Tobin, 1987).	.16
Hidden Figures Test x chemical calculations test (Chandran, Treagust & Tobin, 1987).	.08
Hidden Figures Text x laboratory applications test (Chandran, Treagust & Tobin, 1987).	.04

ACHIEVEMENT X MENTAL CAPACITY	
MEAN =	.21
STANDARD DEVIATION =	.20
NUMBER =	8

Figural Intersection Test x course grade (Roth, 1990).	.40
Figural Intersection Test x ACER test items (Chandran, Treagust & Tobin, 1987).	.07
Figural Intersection Test x post-test (Lawson, 1983).	.05
Figural Intersection Test x chemical calculations (Niaz & Lawson, 1985).	.28
Figural Intersection Test x chemical calculations (Chandran, Treagust & Tobin, 1987).	.06
Figural Intersection Test x chemical calculations (Niaz & Robinson, 1992).	.21
Figural Intersection Test x laboratory applications test (Chandran, Treagust & Tobin, 1987).	.05
Ratio Span Test x examination scores (Roth, 1990).	.58

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ACHIEVEMENT X PRIOR KNOWLEDGE	
MEAN =	.39
STANDARD DEVIATION =	.12
NUMBER =	8
California Achievement Test-science x post-test (Kubota & Olstad, 1991).	.54
Science pre-test x science post-test (Lawson, 1983).	.36
ACER item bank pre-test x chemical calculations (Chandran, Treagust & Tobin, 1987).	.21
Acer item bank pre-test x laboratory applications (Chandran, Treagust & Tobin, 1987).	.26
College Board pre-test x College Board post-test (Stanley & Stanley, 1986).	.48
Science pre-test x science post-test (Lawson & Worsnop, 1992).	.46
Biology 10 grade x Biology 11/13 grade (Biermann & Sarinsky, 1989).	.48
Iowa Test of Basic Skills-science x course grade (Harty, Hamrick & Samuel, 1985).	.31

ACHIEVEMENT X QUANTITATIVE REASONING	
MEAN =	.35
STANDARD DEVIATION =	.22
NUMBER =	14
Stanford Achievement Test-math x Stanford Achievement Test-science (Ronning, McCurdy & Ballinger, 1984).	.70
Cognitive Abilities Test-quantitative x Iowa Test of Basic Skills-science (Harty, Hamrick & Samuel, 1985).	.34
SAT math x HS chemistry grade (DeBoer, 1987).	.09
SAT math x College chemistry grade (DeBoer, 1987).	.43
CAT quantitative x HS science GPA (Haury, 1989).	.45
Biomathematics Skills Test x Advanced Placement Biology Examination (Marsh & Anderson, 1989).	-.18
Cognitive Abilities Test-quantitative x course grade (Harty, Hamrick & Samuel, 1985).	.38
CUNY Math Skills Test x course grade (Biermann & Sarinsky, 1989).	.28
Test of math skills x course grade (Hudson, 1986).	.24
Elementary Algebra Skills Test x course grade (McCammon, Golden & Wuensch, 1988).	.32
Arithmetic Skills Test x course grade (McCammon, Golden & Wuensch, 1988).	.30
Biomathematics Skills Test x biology achievement test (Marsh & Anderson, 1989).	.45
Math achievement x Science achievement (Jacobowitz, 1983).	.67

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Numerical inductive reasoning x examination scores (Roth, 1990).	.45

ACHIEVEMENT X SCIENTIFIC REASONING

MEAN = .40
STANDARD DEVIATION = .16
NUMBER = 6

NAEP reasoning questions x NAEP achievement (Welch, Walberg & Fraser, 1986).	.48
Process of Biological Investigations Test x SRA science (Germann, 1989).	.56
Test of Integrated Process Skills x SRA science (Germann, 1989).	.53
Open-ended reasoning problems x Stanford Achievement Test (Ronning, McCurdy & Ballinger, 1984).	.42

ACHIEVEMENT X SPATIAL REASONING

MEAN = .41
STANDARD DEVIATION = .22
NUMBER = 5

Card Rotations Test x GPA (Wittig, Sasse & Giacomi, 1984).	.44
DAT Mechanical Reasoning x GPA (Wittig, Sasse & Giacomi, 1984).	.57
DAT Spatial Relations x GPA (Wittig, Sasse & Giacomi, 1984).	.67
Purdue Visualization of Rotations x exam grade (Carter, LaRue & Bodner, 1987).	.15
Purdue Visualization of Rotations x examination grades (Pribyl & Bodner, 1987).	.24

ACHIEVEMENT X VERBAL REASONING

MEAN = .40
STANDARD DEVIATION = .25
NUMBER = 4

Stanford Achievement Test-vocabulary x Stanford Achievement Test-science (Ronning, McCurdy & Ballinger, 1984)	.73
Cognitive Abilities Test-verbal x Iowa Test of Basic Skills-science (Harty, Hamrick & Samuel, 1985).	.41
Cognitive Abilities Test-verbal, x class grade (Harty, Hamrick & Samuel, 1985).	.36
Descriptive Test for Language Skills x course grade (Biermann & Sarinsky, 1989).	.11

ABILITY X COGNITIVE LEVEL

MEAN =	.38
STANDARD DEVIATION =	.20
NUMBER =	6

Propositional Logic Test x Developing Cognitive Abilities Test (Baker & Piburn, 1991).	.27
Test of Formal Reasoning x Raven's Progressive Matrices (Niaz, 1991).	.33
Classroom Test of Formal Reasoning x Shipley-Hartford Intelligence-verbal (Lawson & Thompson, 1988).	.43
Classroom Test of Formal Reasoning x Shipley-Hartford Intelligence-verbal (Mitchell & Lawson, 1988).	.11
Lawson's Test of Formal Operations x Short-Form Test of Academic Aptitude (Stuessy, 1989).	.48
Lawson Classroom Test of Formal Reasoning x Raven Progressive Matrices (Niaz & Lawson, 1985).	.69

ABILITY X FIELD-DEPENDENCE/INDEPENDENCE

MEAN =	.48
STANDARD DEVIATION =	.16
NUMBER =	6

Group Embedded Figures Test x Otis-Lennon Intelligence Test (Ronning, McCurdy & Ballinger, 1984).	.62
Group Embedded Figures Test x Raven Progressive Matrices (Niaz, 1991).	.46
Gottschaldt Figures Test x Raven Progressive Matrices (Niaz & Lawson, 1985).	.49
Gottschaldt Figures Test x Schipley-Hartford Intelligence Test (Lawson & Thompson, 1988).	.32
Group Embedded Figures Test x Schipley-Hartford Intelligence Test-verbal (Mitchell & Lawson, 1988).	.71
Concealed Figures Test x Short Form Test of Academic Aptitude (Stuessy, 1989).	.30

ABILITY X MENTAL CAPACITY

MEAN =	.32
STANDARD DEVIATION =	.11
NUMBER =	4

Figural Intersection Test x Raven Progressive Matrices (Niaz, 1991).	.33
Figural Intersection Test x Raven Progressive Matrices (Niaz & Lawson, 1985).	.46
Figural Intersections Test x Shipley-Hartford Intelligence Test-verbal (Lawson & Thompson, 1988).	.18
Figural Intersections Test x Shipley-Hartford Intelligence Test-verbal (Mitchell & Lawson, 1988).	.30

ABILITY X PRIOR KNOWLEDGE	MEAN =-.03 STANDARD DEVIATION = .08 NUMBER = 2
Genetics pre-test x Shipley-Hartford Intelligence Test-verbal (Mitchell & Lawson, 1988).	-.09
Number of biology misconceptions x Shipley-Hartford Intelligence-Verbal (Lawson & Thompson, 1988).	.03
ABILITY X QUANTITATIVE REASONING	MEAN = .55 STANDARD DEVIATION = .24 NUMBER = 3
Stanford Achievement Test-math x Otis-Lennon Intelligence Test-math (Ronning, McCurdy & Ballinger, 1984).	.83
Elementary Math Skills Test x Primary Mental Abilities (McCammon, Golden & Wuensch, 1988).	.38
Arithmetic Skills Test x Primary Mental Abilities Test (McCammon, Golden & Wuensch, 1988).	.44
ABILITY X SCIENTIFIC REASONING	MEAN = .54 NUMBER = 1
Open-ended reasoning problems x Otis-Lennon Intelligence Test (Ronning, McCurdy & Ballinger, 1984).	.54
ABILITY X SPATIAL REASONING	MEAN = .53 STANDARD DEVIATION = .09 NUMBER = 4
Paper Form Board x DAT Abstract Reasoning (Wittig, Sasse & Giacomi, 1984).	.48
DAT Mechanical Reasoning x DAT Abstract Reasoning (Wittig, Sasse & Giacomi, 1984).	.48
DAT Spatial Relations x DAT Abstract Reasoning (Wittig, Sasse & Giacomi, 1984).	.67
Card Rotations x DAT Abstract Reasoning (Wittig, Sasse & Giacomi, 1984).	.50
ABILITY X VERBAL REASONING	MEAN = .74 NUMBER = 1
Stanford Achievement Test-verbal x Otis-Lennon Intelligence Test (Ronning, McCurdy & Ballinger, 1984).	.74

COGNITIVE LEVEL X FIELD DEPENDENCE/INDEPENDENCE	
MEAN =	.40
STANDARD DEVIATION =	.10
NUMBER =	12
Group Embedded Figures Test x Group Assessment of Logical Thinking (Niaz & Robinson, 1992).	.39
Concealed Figures Test x Lawson's Test of Formal Operations (Stuessy, 1989).	.51
Gottschaldt Figures Test x Lawson's Test of Formal (Niaz & Lawson, 1985).	.52
Gottschaldt Figures Test x Classroom Test of Formal Reasoning (Lawson & Thompson, 1988).	.36
Group Embedded Figures Test x Classroom Test of Formal Reasoning (Mitchell & Lawson, 1988).	.30
Group Embedded Figures Test x Test of Formal Reasoning (Niaz, 1991).	.48
Group Embedded Figures Test x Lawson Classroom Test of Formal Reasoning (Lawson, 1983).	.40
Group Embedded Figures Test x Longeot Test (Lopez-Ruperez, Palacios & Sanchez, 1991).	.21
Hidden Figures Test x Test of Logical Thinking (Chandran, Treagust & Tobin, 1987).	.32
Find-a-Shape x Test of Logical Thinking (Staver & Jacks, 1988).	.42
Group Embedded Figures Test x Proportional Reasoning (Niaz, 1989).	.50
Group Embedded Figures Test x Proportional Reasoning (Roth, 1990).	.35

COGNITIVE LEVEL X MENTAL CAPACITY	
MEAN =	.37
STANDARD DEVIATION =	.12
NUMBER =	10
Figural Intersections Test x Group Assessment of Logical Thinking (Niaz & Robinson, 1992).	.39
Figural Intersections Test x Lawson Classroom Test of Formal Reasoning (Lawson, 1983).	.42
Figural Intersections Test x Test of Formal Reasoning (Niaz, 1991).	.48
Figural Intersections Test x Lawson Classroom Test of Formal Reasoning (Niaz & lawson, 1985).	.33
Figural Intersections Test x Classroom Test of Formal Reasoning (Lawson & Thompson, 1988).	.21
Figural Intersection Test x Classroom Test of Formal Reasoning (Mitchell & Lawson, 1988).	.28
Figural Intersections Test x Test of Logical Thinking (Chandran, Treagust & Tobin, 1987).	.20
Figural Intersections Test x proportionality tasks (Roth, 1990).	.43
Reading Span Test x Test of Logical Thinking Staver & Jacks, 1988).	.36

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Ratio-Span Test x proportionality tasks (Roth, 1990).	.61

COGNITIVE LEVEL X PRIOR KNOWLEDGE

MEAN = .37
STANDARD DEVIATION = .08
NUMBER = 8

Genetics test x Classroom Test of Formal Reasoning (Mitchell & Lawson, 1988).	.26
Evolution test x Lawson Classroom Test of Formal Reasoning (Lawson, 1983).	.31
Pretest x Lawson Classroom Test of Scientific Reasoning (Lawson & Worsnop, 1992).	.39
Physical Changes Concepts Test (T form) x Test of Logical Thinking (Haidar & Abraham, 1991).	.37
Physical Changes Concepts Test (A Form) x Test of Logical Thinking (Haidar & Abraham, 1991).	.46
ACER test bank items (pretest) x Test of Logical Thinking (Chandran, Treagust & Tobin, 1987).	.32
Prior Knowledge (formulas) x Test of Logical Thinking (Staver & Jacks, 1988).	.48
Number of biology misconceptions x Classroom Test of Formal Reasoning (Lawson & Thompson, 1988).	-.41

COGNITIVE LEVEL X QUANTITATIVE REASONING

MEAN = .50
STANDARD DEVIATION = .09
NUMBER = 4

SRA Math x Classroom Test of Formal Operations (Germann, 1989).	.63
Course grade (math) x Group Assessment of Logical Thinking (Bitner, 1991).	.41
Writing and solving equations x Lawson Test of Formal Reasoning, 1989).	.51
Numerical Inductive Reasoning x proportionality tasks (Roth, 1990)	.47

COGNITIVE LEVEL X SCIENTIFIC REASONING

MEAN = .57
STANDARD DEVIATION = .06
NUMBER = 3

Test of Integrated Process Skills x Classroom Test of Formal Operations (Germann, 1989).	.51
Processes of Biological Investigation x Classroom Test of Formal Operations (Germann, 1989).	.61
Test of Integrated Process Skills x Test of Logical Thinking (Padilla, Okey & Dillashaw, 1983).	.60

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COGNITIVE LEVEL X SPATIAL REASONING	MEAN = .57 NUMBER = 1
Purdue Visualization of Rotations x Test of Logical Thinking (Staver & Jacks, 1988).	.57
COGNITIVE LEVEL X VERBAL REASONING	MEAN = .47 NUMBER = 1
SRA Reading x Classroom Test of Formal Operations (Germann, 1989).	.47
FIELD DEPENDENCE/INDEPENDENCE X MENTAL CAPACITY	MEAN = .37 STANDARD DEVIATION = .15 NUMBER = 12
Figural Intersection Test x Gottschaldt Figures Test (Lawson & Thompson, 1988).	.42
Figural Intersection Test x Group Embedded Figures Test (Lawson, 1983).	.36
Figural Intersection Test x Group Embedded Figures Test (Mitchell & Lawson, 1988).	.30
Figural Intersection Test x Group Embedded Figures Test (Niaz, 1991).	.37
Figural Intersection Test x Group Embedded Figures Test (Niaz & Robinson, 1992).	.50
Figural Intersection Test x Group Embedded Figures Test (Roth, 1990).	.62
Figural Intersection Test x Group Embedded Figures Test Roth & Milkent, 1991).	.61
Figural Intersection Test x Hidden Figures Test (Chandran, Treagust & Tobin, 1987).	.18
Ratio Span Test x Group Embedded Figures Test (Roth & Milkent, 1991).	.21
Backward Digit Span x Group Embedded Figures Test Roth & Milkent, 1991).	.22
Reading Span Test x Find-a-Shape (Staver & Jacks, 1988).	.22
Figural Intersection Test x Gottschaldt Figures Test	.38
FIELD DEPENDENCE/INDEPENDENCE X PRIOR KNOWLEDGE	MEAN = .15 STANDARD DEVIATION = .10 NUMBER = 5
Prior knowledge (formulas) x Find-a-Shape (Staver & Jacks, 1988).	.12
Evolution pre-test x Group Embedded Figures Test (Lawson, 1983).	.32

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Genetics test x Group Embedded Figures Test (Mitchell & Lawson, 1988).	.12
ACER item bank (pretest) x Hidden Figures Test (Chandran, Treagust & Tobin, 1987).	.11
Number of biology misconceptions x Gottschaldt Figures Test (Lawson & Thompson, 1988).	

FIELD DEPENDENCE/INDEPENDENCE X QUANTITATIVE REASONING MEAN = .51
STANDARD DEVIATION = .01
NUMBER = 2

Stanford Achievement Test-math x Group Embedded Figures Test (Ronning, McCurdy & Ballinger, 1984).	.51
Numerical Inductive Reasoning x Group Embedded Figures Test (Roth, 1990).	.52

FIELD DEPENDENCE-INDEPENDENCE X SCIENTIFIC REASONING MEAN = .47
NUMBER = 1

Open-ended science problems x Group Embedded Figures Test (Ronning, mcCurdy & Ballinger, 1984).	.47

FIELD-DEPENDENCE/INDEPENDENCE X SPATIAL REASONING MEAN = .62
NUMBER = 1

Purdue Visualization of Rotations x Find· .-Shape (Staver & Jacks, 1988).	.62

FIELD-DEPENDENCE/INDEPENDENCE X VERBAL REASONING MEAN = .42
NUMBER = 1

Stanford Achievement Test-vocabulary x Group Embedded Figures Test (Ronning, McCurdy & Ballinger, 1984).	.42

MENTAL CAPACITY X PRIOR KNOWLEDGE MEAN = .13
STANDARD DEVIATION = .10
NUMBER = 5

Genetics test x Figural Intersections Test (Mitchell & Lawson, 1988).	.27
ACER test-bank pre-test x Figural Intersections Test (Chandran, Treagust & Tobin, 1987).	.07
Evolution pre-test x Figural Intersections Test (Lawson, 1983).	.13
Prior knowledge (formulas) x Reading Span Test (Staver & Jacks, 1988).	.02

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Figural Intersections Test x number of biology misconceptions (Lawson & Thompson, 1988).	-.17

<u>MENTAL CAPACITY X QUANTITATIVE REASONING</u>

MEAN = .58
STANDARD DEVIATION = .13
NUMBER = 3

Numerical Inductive Reasoning x Figural Intersections Test (Roth, 1990)	.44
Numerical Inductive Reasoning x Ratio Span Test (Roth, 1990).	.61
Numerical Inductive Reasoning x Ratio Span Test (Roth, 1991).	.70

<u>MENTAL CAPACITY X SPATIAL REASONING</u>

MEAN = .10
NUMBER = 1

Purdue Visualization of Rotations x Reading Span Test (Staver & Jacks, 1988).	.10

<u>PRIOR KNOWLEDGE X SPATIAL REASONING</u>

MEAN = .33
NUMBER = 1

Purdue Visualization of Rotations x Prior knowledge -formulas (Staver & Jacks, 1988).	.33

<u>QUANTITATIVE REASONING X SCIENTIFIC REASONING</u>

MEAN = .49
STANDARD DEVIATION = .05
NUMBER = 3

Open-ended science questions x Stanford Achievement Test -Math (Ronning, McCurdy & Ballinger, 1984).	.46
Process of Biological Investigations Test x SRA math (Germann, 1989).	.54
Test of Integrated Process Skills x SRA math Germann, 1989)	.46

<u>QUANTITATIVE REASONING X VERBAL REASONING</u>

MEAN = .54
STANDARD DEVIATION = .26
NUMBER = 3

Cognitive Abilities Test-verbal x Cognitive Abilities Test-quantitative (Harty, Hamrick & Samuel, 1985).	.73
Nelson-Denny Reading Test x Biomathematics Skills Test (Marsh & Anderson, 1989).	.25
Stanford Achievement Test-vocabulary x Stanford Achievement Test-mathematics (Ronning, McCurdy & Ballinger, 1984).	.64

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SCIENTIFIC REASONING X VERBAL REASONING	
MEAN =	.48
STANDARD DEVIATION =	.13
NUMBER =	4

SRA Reading x Test of Integrated Process Skills (Germann, 1989).	.56
SRA Reading x Process of Biological Investigation Test (Germann, 1989)	.59
Stanford Achievement Test-vocabulary x open-ended science (Ronning, McCurdy & Ballinger, 1984).	.47
Test of Integrated Process Skills x Nelson-Denny Reading Test (Faryniarz & Lockwood, 1992).	.31